GEOELECTRIC INVESTIGATION OF HOT SPRINGS IN WESTERN MAHARASHTRA

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ABSTRACT

Thermal springs are the surface manifestations of the subsurface geothermal energy which has attained significant attention in recent years as an alternate energy source. The state of Maharashtra in India is characterized by superficial thermal manifestations represented by numerous hot springs, mostly restricted in the western coast. An attempt is made here to study the possible geothermal sources and to establish the subsurface structure and aquifer system over three hot springs in Ratnagiri district in western Maharashtra based on the analysis of vertical electrical resistivity soundings (VES). Resistivity contouring has been carried out for different electrode spacing i.e. AB/2= 5m, 15m, 30m, 50m and 100m which provides the variation of resistivity at five different horizons. A low apparent resistivity of the order of 10-40 Ω-m is prominent at shallow depth of 5m (between 17.2 to 17.25 latitude), which coincides with the location of Tural hot spring. This conducting feature is also observed at other depths. It is also evident that the low resistivity at Tural is spreading as the depth increases. It is possible that the thermal spring source at Tural is located at greater depths. The Aravali hot spring is characterized by a minor low apparent resistivity at all the depths indicating that this is weak compared to the Tural spring. The Tural spring is much hotter than the Aravali one at the surface along with gas emission. The 2-D geoelectrical sections delineated the geometry of the aquifer bodies associated with the hot springs. A close grid magnetic study will further elucidate the geothermal resources and delineate the structural setting of the area.

KEYWORDS: Resistivity, hot spring, aquifer, western Maharashtra

INTRODUCTION

Thermal springs are the surface manifestations of the subsurface geothermal energy which has attained significant attention in recent years as an alternate energy source. The state of Maharashtra in India is characterized by superficial thermal manifestations represented by numerous hot springs, mostly restricted in the western coast. The west coast thermal province extends over a linear stretch of about 350 km and width of about 20-30 km (Padhi *et al.*; 1995, Deshpande; 1998, Minissale *et al.*; 2000). These springs trend NNW-SSE and are parallel to the Sahyadri mountain chain and the west coast. All these hot springs are located in the Deccan basalts from Ganeshpuri in the north to Rajapur in the south (Fig. 1).

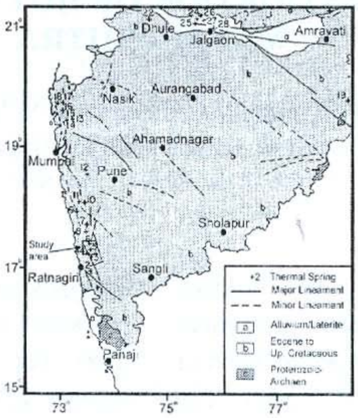


Figure 1. Geological map of the study region

It has been reported by (Padhi *et al.* 1995) that most of the hot springs is of low to intermediate enthalpy at shallow depths.

Geothermal springs have been explored using geoelectrical and geopotential methods by several workers (Henkel *et al.;* 1977, Bernard *et al.;* 1991, Benson *et al.*; 1997, Cagler *et al.;* 1999, Majumdar *et al.*; 2000, Baranwal and Sharma; 2006, Routh *et al.*; 2006, Harinarayana *et al.*; 2006). However the geophysical studies in west coast of Maharashtra are limited to geochemistry and geothermometry. An attempt is made here to study the possible geothermal sources over three hot springs in Ratnagiri district in western Maharashtra based on the analysis of vertical electrical resistivity soundings (VES) at five places in the vicinity of the hot springs, to establish the subsurface structure and aquifer. system (Fig. 2).

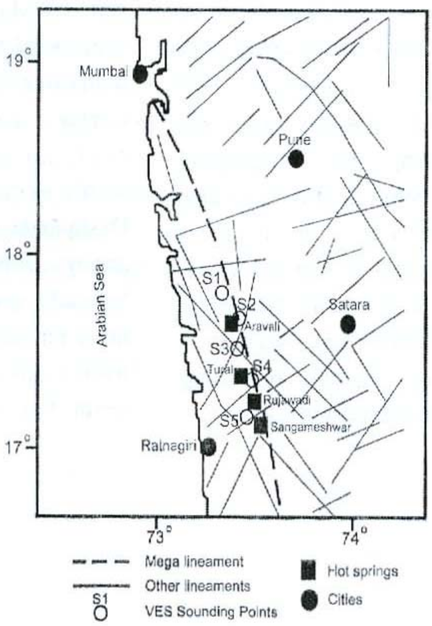


Figure 2. Schematic map showing the location of lineaments and hot springs in the study region. Also shown are the vertical electrical sounding points.

Geology And Geochemistry Of The Region

The Deccan Volcanic Province (DVP) is covered by the fissure erupted basaltic magma, which has spread over an area of about half a million sq.km in the western part of the Indian peninsula. The thickness of the basalts ranges from a few meters on the east to about 3000 meters on the west and has suffered intense tectonic activity since the Tertiary period. The isostatic imbalance caused by the nearly 10^{15} tons of the basalts and the subsequent weathering and erosional processes have made a significant contribution to the tectonic evolution of the DVP (Widdowson and Mitchell; 1999). Two different types of lave flows have been documented (Deshpande; 1998). These are the pahoehoe type and the Aa type. The southern part of Ratnagiri and Sindhudurg districts are characterized by the Aa type flows whereas the pahoehoe type flow is confined to the northern part of Thane district (Sarolkar; 2005). The basaltic flows show a gentle dip of less than 1^{o} to the east whereas in the close vicinity of the west coast, relatively higher dips of about 4^{o} are observed. Some evidences of post-trappean faulting in recent times and rejuvenation of the DVP for accumulation of tectonic stress are evidenced by a series of hot springs parallel to the coast (Athavale; 1975).

The evolution of West coast of India is the result of a series of Mesozoic rifting events (late Jurassic - early Cretaceous) beginning with detachment of Madagascar (Storey *et al.*; 1995). The formation of present Indian margin was the result of a ridge jump, which detached India from the Seychelles bank at the time of the Deccan volcanism. The break-up of the Gondwana Super-continent resulted into the formation of India as a part. The northward flight of India, the sudden burst of volcanic activity, the uplift of the Peninsula and its break-up, the creation of the Arabian Sea and the Sahyadri scarp paralleling the West Coast – all these together make a fascinating story of landscape development of the Konkan coastal plain (Chandrasekharam; 1985). Dessai and Viegas (1995) are of the opinion that the western margin of India represents an extensional fault structure. This view has also been reported from magnetotelluric studies in the western part of the DVP, which show indications of extensional tectonics in the south (Gokarn *et al.*; 2003). The straight-line pattern of the West coast of India and the Western Ghats scarp paralleling the coast are very striking. Many geo-scientists are of the view that the abrupt termination of the Deccan Trap flows along the line of the Western Ghats points to Cenozoic uplift, rifting and down faulting. (Athavale 1975) suggested the existence of a zone of faults located to the west of the Sahyadri range and running nearly parallel to the western coast of India. It is also proposed that the increase in seismic activity in this region is due to the release of strain accumulated in the zones of faults. The induced seepage in the approximately NE trending fractures contributes enormous quantities of water into the EW running Vashisthi and other rivers present here. Based on Landsat imagery, a number of linear features were identified over the Konkan coast (Qureshy; 1982, Powar; 1981).

The major hot springs in the west coast of Maharashtra are Rajapur in Sindhudurg district, Unhavre, Tural, Aravli and Rajawadi in Ratnagiri district, Sativli and Ganeshpuri in Thane district. Most of these hot springs have temperatures ranging between 42°C to 71°C. Gaseous activity has been observed in some of these springs. The thermal water from these hot springs is alkali chloride type with high sulphate content except in the Rajapur spring, which discharges bicarbonate water (Sarolkar; 2005). The quartz geothermometry studies reported 107° C in Ganeshpuri to 127° C in Unhavre, while by sodium-potassium method; temperatures vary from 113°C in Rajawadi to 170° C in Tural. The hydrothermal minerals indicate possibility of getting higher temperatures at greater depths.

The hot springs under the present studies are Aravali, Tural and Rajawadi (Fig. 2). These springs are located about 10-18 km north of Sangameshwar, on the banks of tributary joining Sashtri River. As seen from Fig. 2, the hot springs is aligned along an N 20° W - S 20° E fracture zone/mega lineament. It may be noted here that this region is seismically active with small to medium earthquakes occurring frequently. Sporadic gaseous activities in the form of bubbles are reported from the Tural and Rajawadi hot spring. At Tural, hot water of about 60° C is discharged at the rate of 250 lpm whereas at Rajawadi the temperatures are lower (about 55° C) and the discharge rate is about 50 lpm. A temperature of 41° C has been recorded at Aravali hot spring with water flowing at the rate of about 50 lpm.

The geochemical studies of water from these springs (Sarolkar; 2005) suggest that they are sodium chloride type with rich sulphate content. Chloride content at Tural is rather high at 340 ppm. However the sulphate content at Tural is 100 ppm. The sodium content at Tural is 244 ppm whereas it is 470 ppm in Rajawadi. Silicon dioxide at Tural and Rajawadi are 84 and 88 ppm respectively. It is reported by Minissale et. al. (2000) that the thermal springs in the west coast has very high salinity of the order of 1000-4000 mg/kg. Thus the high chloride content at Tural suggests direct access to geothermal reservoir or mixing of sea water with the thermal water. The temperature-depth curves of boreholes at Tural-Rajawadi springs are shown in Fig. 3 (after Ravi Shanker *et al.*; 1991).

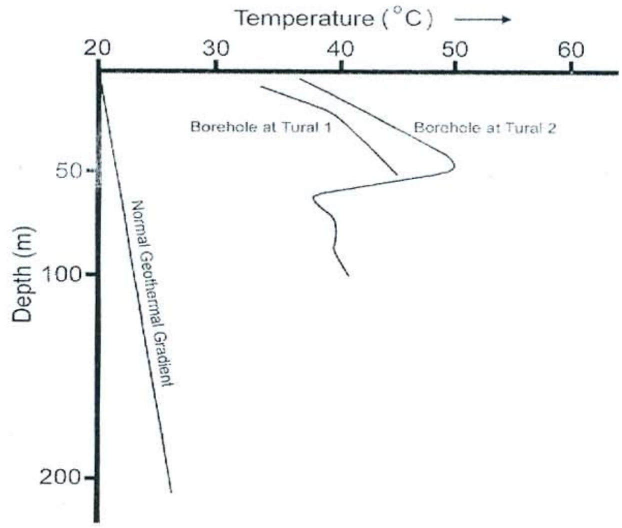


Figure 3. Temperature-depth profile at Tural hot spring (redrawn after Ravishankar *et al.*; 1991).

There are two exploratory boreholes in Tural-Rajawadi region. These suggests that the temperature increases from 34° C at the surface to about 45° C at depths of about 50m at TR-1. At TR-2, the surface temperature is 36° C which rises to 41° C at depths of 100m. However, maximum temperature of about 50° C is recorded at depths of 40m (Ravi Shanker *et al.*; 1991). It is also reported that the salinity of hot spring water increases with temperature (Starinsky *et al.*; 1979, Tanaka *et al.*; 1984).

Resistivity Studies – Methodology and Analysis

As mentioned earlier, the geophysical investigation incorporated use of electrical resistivity method. The VES electrical resistivity studies is based on measuring the potentials between one electrode pair while transmitting direct current (DC) between another electrode pair. The depth of penetration is proportional to the separation between the electrodes, in homogeneous ground, and varying the electrode separation provides information about the stratification of the ground (Dahlin; 2001). This method is carried out to decipher problems of groundwater in the hard formation aquifer such as the Deccan Trap region, as an inexpensive and useful method.

The VES was carried out in the study area with a SSR-MP-ATS resistivity meter supplied by IGIS, Hyderabad. The location of electrical profiles and soundings is shown in Fig. 2. Electrical resistivity soundings were conducted at five different locations by using the Schlumberger array for delineating vertical distribution of water bearing zones, constituting the aquifer bodies in this region. Of the five soundings, two were carried out across the hot springs Aravali and Tural. The other three were away from the hot springs. The site around Rajawadi hot spring was marshy and thus it was not possible to conduct a sounding there. The Schlumberger soundings were carried with maximum current electrode spacing (AB) of 200 m (AB/2=100 m). The field data acquisition was generally carried out by moving two or four of the electrodes used, between each measurement. The resulting geoelectrical layer succession was used for predicting various conducting zones based on true resistivities. Employing Schlumberger configuration the apparent resistivity was calculated (Kearey and Brooks; 1988) as,

$$\rho a = \pi [(L/2)2 - (b/2)2] / b * V/I$$

Where, L and b is the current and potential electrode spacing respectively.

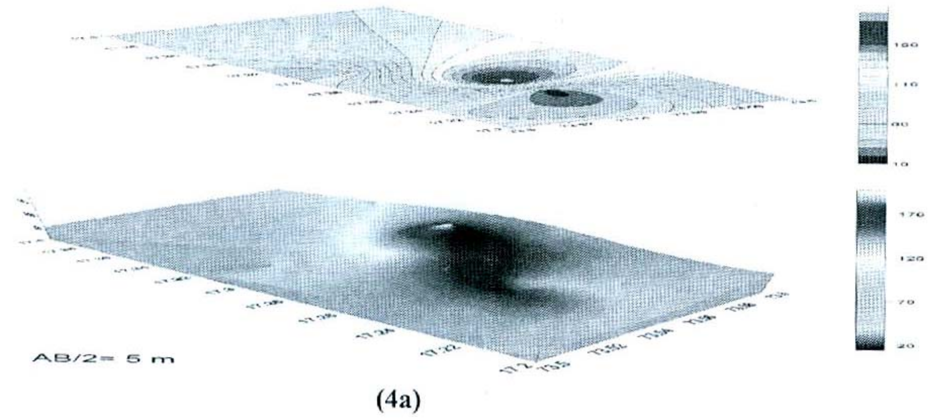
The data obtained from the field was processed and modeled using IPI2WIN software, version 3.0.1.a7.01.03 (Bobachev; 2003) for interactive semi-automated interpretation.

Here a 2D coverage of soundings spread over the entire region has been made. The resistivity distribution over this region put qualitatively corresponds to variations of the resistivity at different depths. Resistivity contouring has been carried out for different electrode spacing i.e. AB/2= 5m, 15m, 30m, 50m and 100m which provides the variation of resistivity at five different horizons.

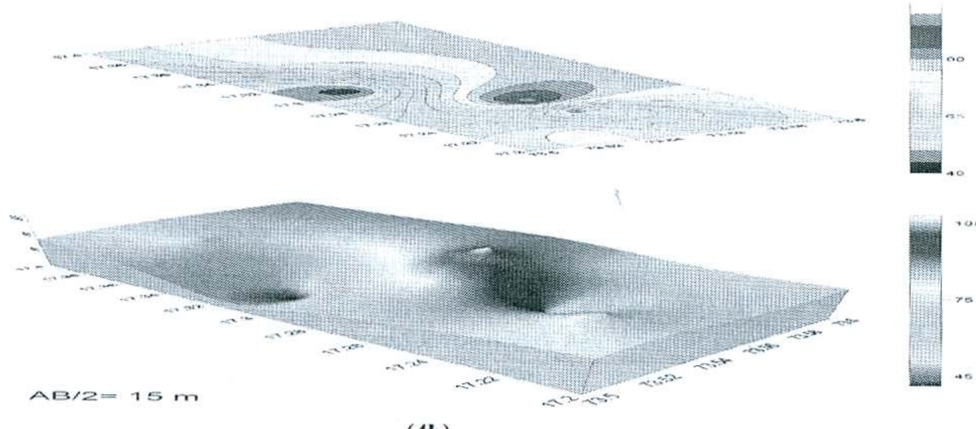
RESULTS OF RESISTIVITY DATA

Spatial distribution of apparent resistivity:

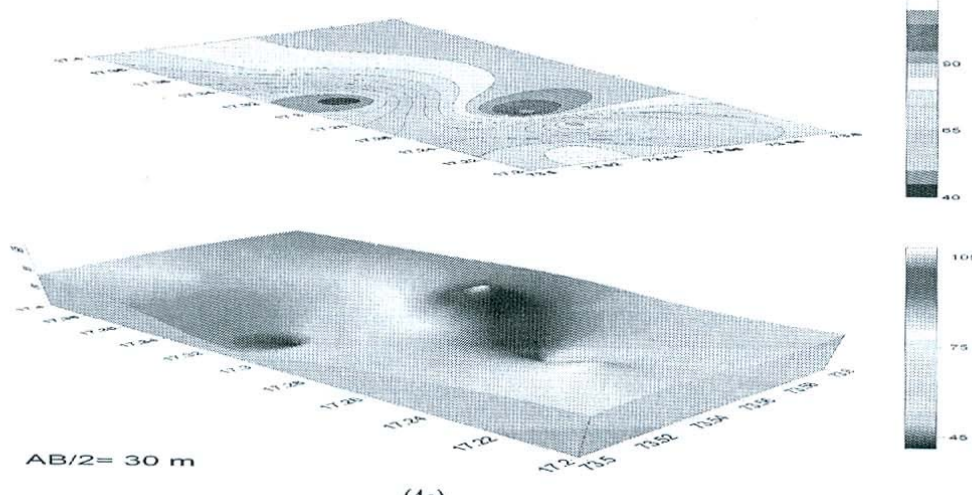
The spatial distribution of the apparent resistivity of all the five VES sounding points over the entire region was evaluated by the kriging method using SURFER software. The resistivity distribution over this region put qualitatively corresponds to variations of the resistivity at different depths. Resistivity contouring has been carried out for different electrode spacing i.e. AB/2= 5m, 15m, 30m, 50m and 100m which provides the variation of resistivity at five different horizons (Figs. 4 a-e). Also shown in these figures is the 3-D cross-section of the entire study region. A low apparent resistivity of the order of 10-40 Ω-m is observed at shallow depth of 5m (between 17.20 to 17.25 latitude), which coincides with the location of Tural hot spring. This conducting feature is also observed at 15, 30, 50 and 100m with resistivity values in the range 30-50, 40-60, 50-60 and 42-52 Ω-m respectively.



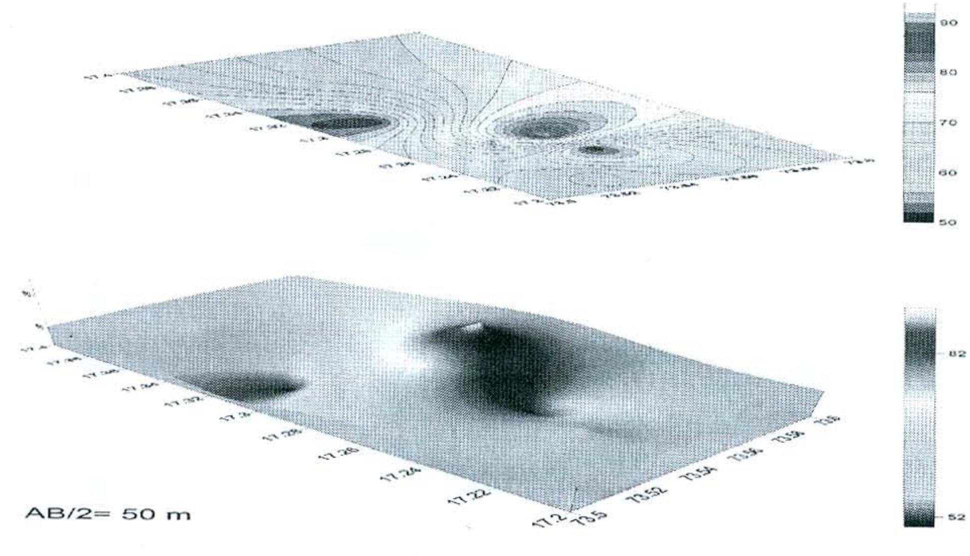
(4a)


90
65
40
105
75
45
AB/2= 15 m
17.2
17.22
17.24
73.5
73.52
73.54

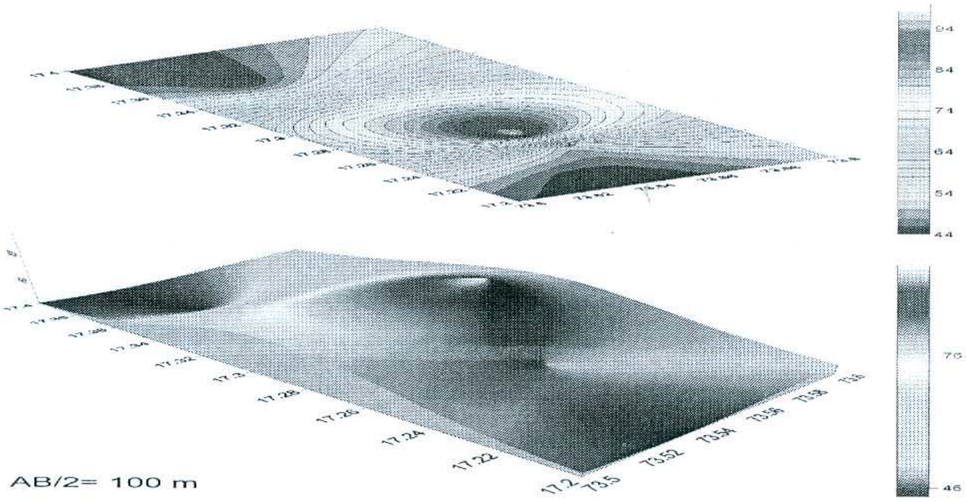
(4b)


90
65
40
105
75
45
AB/2= 30 m
17.2
17.22
17.24
73.5
73.52
73.54

(4c)


90
80
70
60
50
82
52
AB/2= 50 m
17.2
17.22
17.24
73.5
73.52
73.54

(4d)



(4e)

Figure 4. (a-e): 2D contour map and 3D surface map for AB/2= 5 m, 15 m, 30 m, 50 m and 100 m.

The Aravali hot spring, located at 17.3 latitude, indicates a minor low apparent resistivity at all the depths in the resistivity band of 10-60 Ω-m. However, it can be seen from Fig. 4 that the signature of the Aravali spring is weak compared to the Tural spring. It may be noted here that the Tural spring is much hotter than the Aravali one at the surface along with gas emission. It is also evident from Fig. 4 that the low resistivity at Tural is spreading as the depth increases.

Due to unavailability of proper site, VES was not carried out at Rajawadi. However, the aerial distance between Tural and Rajawadi springs are about 500m. Thus the wide low apparent resistivity observed from 17.20 to 17.25 latitude at depths of 100m may have the contribution from Tural as well as Rajawadi thermal springs.

2-D geoelectrical section

The 2-D geoelectrical section has been generated in order to understand the geometry of the aquifer developed in and around the hot springs (Fig. 5). Longitudinal geoelectric section over the hot springs and its surroundings shows the presence of an oval shaped depression up to depths of about 40 m at VES 4 having resistivities in the range of 10 Ω-m, characterizing aquifer bodies associated with the Tural and Rajawadi springs. This conducting feature tapers at both sides of the profile. The lower part of VES 4 with resistivities in the range of 60 Ω-m extends towards south. A low resistivity zone is observed at VES 2 which corresponds to the Aravali spring. This feature with resistivity in the range of 20-30 Ω-m is also oval in shape albeit weak in nature. The lower part of the aquifer body extends towards north at depths of 50 m. It is pertinent to mention here that the E-W flowing Gad River is to the north of Aravali hot spring. It may be noted here that the physiographic position of VES 5, VES 3 and VES 1 are at higher elevation which is clearly reflected in the pseudo cross-section with resistivities in the range of 180 Ω-m up to about 20 m depth. These comprise of hard rocks at shallow depths.

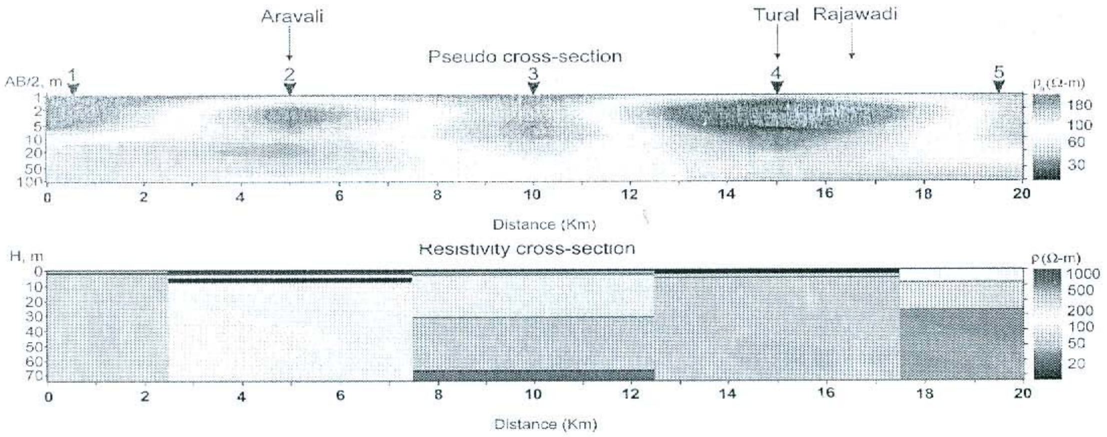


Figure 5. Longitudinal geoelectrical section over the study area

DISCUSSIONS AND CONCLUSION

As discussed earlier, the signature of Tural, Rajawadi and Aravali hot springs is quite well delineated in both the resistivity contouring and the 2-D cross section, the Tural spring being more prominent The Chiplun mega lineament along with a number of other minor lineaments is cutting this region. Also it is reported that the chloride content at Tural spring is very high (340 ppm) (Sarolkar; 2005) and has very high salinity (Minissale *et al.;* 2000). Thus it is possible that Tural hot spring is manifested by saline water intrusion at greater depths. The Deccan Traps consists of several lava flows piled up one over the other and are generally characterized by joints, fractures and fissures. These geofeatures can provide good aquifer conditions and can occur at any depths. Thus the ascending thermal water is likely to spread laterally also. In the present study, perhaps this indicates the admixing of thermal water with sea water through the fractures and joints giving rise to enhanced low resistivity at Tural compared to the Aravali hot spring.

From the 2-D geoelectrical section it is observed that the source of the geothermal energy is beyond depths of 100 m. Also the thickness of the low resistive zones is most substantial at the hot springs, VES 2 and VES 4. The thickness of fractured formation is maximum at the hot spring and the depth of the fractured formation extends up to about 50 m from the surface.

The nature of the heat source in relation to the thermal manifestation of this region is not very clear at present. It is possible that the post-trappean tectonic movements which resulted in normal faulting might have facilitated the intrusion of magmatic bodies at shallow depths. However detailed ground magnetic studies over the hot springs and its vicinity will elucidate about the depth to the interface between the hard rock and the fractured zones. Subsequently ground water movement within the subsurface and possible hot spring sources can be identified.

It is observed that there is a continuous and consistent discharge of hot water in the springs here. This is mainly used for bathing and washing purpose. It is suggested that the geothermal resources of these springs can be exploited for generation of electricity, food and agro industry, green housing and tourist resort centers.

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